5-13-2002

Image quality measurement and modeling for digital photography

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Image Quality Measurement and Modeling for Digital Photography

ICIS 2002 Tokyo

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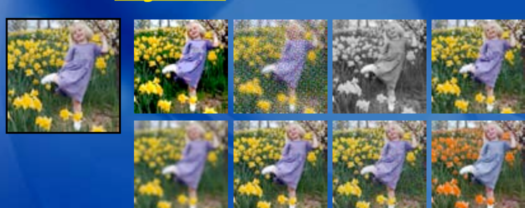
Outline

- Measuring Image Quality
- Colorimetric Approach
- Spatial Vision Approach
- Systems Approach
- Need for a Fundamental Approach for Digital Photography

Color Image Quality

Reductions in image quality correspond to perceptible visual *differences* from some ideal and the *magnitude* of such differences.



Thresholds

Threshold metrics describe the probability of detection of image artifacts.

JNDs — Just Noticeable Differences

Scales

Interval scales of image quality describe the magnitudes of changes in image quality that are clearly perceptible.

Image A is N-units better than Image B.

A greater challenge …

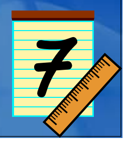


Image Quality Circle

Engeldrum (2000)

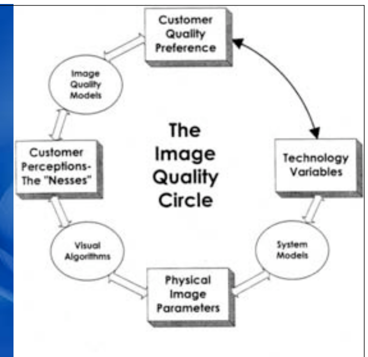


Figure 2.3 - The complete Image Quality Circle showing all the Connecting Links.

Systems vs. Fundamental Approaches

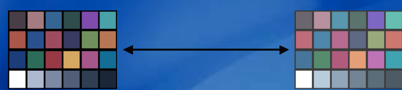
Systems: Relate Technology Variables Directly to Observer Ratings (JNDs or Scales). {Psychophysics & Statistics}

Fundamental: Relate Image Measurements to Observer Quality Scales (or JNDs) Regardless of Image Source {Psychophysics & Vision Modeling}

Historical Approaches

- Colorimetric Measurements
- Spatial Vision Models
- Systems Metrics

Colorimetric Approaches



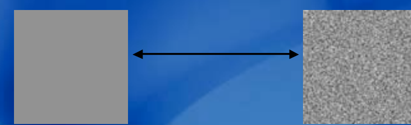
For Simple (Constant) Viewing Conditions:

•CIELAB ΔE_{94} (or CIEDE2000)
•Patch-by-Patch (or Pixel-by-Pixel)
•Min., Mean, Max., Histogram
•Variance, Correlation, etc.

Color Appearance Models Sometimes Applied to More Complex Conditions:

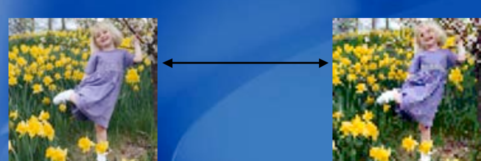
•CIECAM97s (or CIECAM02)

Spatial Vision Approaches



- Models of Spatial Vision (*"Detection Models"*)
- Detectable Differences in Various Spatial Frequency Channels? (Overall?)
- Based on Human CSF / Threshold Data
- *e.g.*, Daly's "Visible Differences Predictor", Lubin's "Sarnoff Model"

Systems Approaches



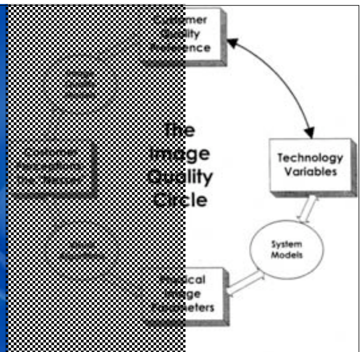
Simple Image Specifications

- Bits per Pixel
- Pixels per Image (or inch, or degree, etc.)
- Noise, Granularity
- Luminance, Contrast, Gamut Volume

Two Image Quality Paradigms

- **Device-Dependent Image Quality**
  - The Systems-Based Approach
- **Device-Independent Image Quality**
  - The Fundamental Approach
  - The Vision-Modeling Approach
  - Image-Appearance Modeling

IQ Circle - Systems



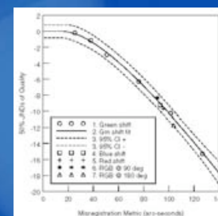
te Image Quality Circle
ng Links.

Device-Dependent IQ

More Comprehensive Systems Approaches

e.g., Keelan *et al.* (2000, 2002) "JND" Predictions

Physical Anchor Scale



Statistical Models to Predict Quality Scale for Single & Multiple Variables

Device-Dependent Image Quality

- Systems approaches to image quality measurement are analogous to device-dependent color specifications (*e.g.*, RGB, CMYK).
- Thus, they represent *device-dependent image quality.*

IQ Circle - Fundamental

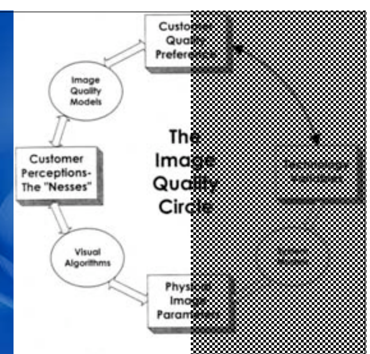
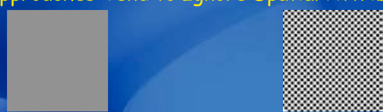


Figure 2.3 - The comple
showing all the Connect

Device-Independent IQ

The Need for a Fundamental Approach

•Color Approaches Tend to Ignore Spatial Attributes



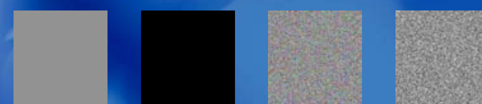
ΔE=50 for each pixel*
ΔIm = 0 for appropriate viewing distance

•Spatial Approaches Tend to Ignore Color Appearance
(Luminance Only, No Adaptation, etc.)

•Image Specifications Tend to Ignore Human Perception

Image Quality as an Interval Scale

Interval scales have no meaningful zero.
(What is zero image quality?)



Reduction in image quality can be a ratio scale.
(Zero reduction in IQ is a sub-threshold difference.)

A Unified Approach

An image quality metric can be derived as a measure of perceived difference from an ideal image.

Alternative: "Image Preference Scale"

Device-Independent Image Quality

Fundamental approaches to image quality measurement are analogous to device-independent color specifications (*e.g.,* XYZ, CIELAB L*a*b*, CIECAM JCh).

Thus, they represent *device-independent image quality.*

ASSERTION: Device-independent image quality is necessary for open digital imaging systems.

Psychophysics & Vision Modeling

Device-Independent Image Quality Requires:

- Psychophysics to Quantify Perceptual Scales
- Vision Modeling to Relate Image Stimuli to Measured Perceptual Scales
- Iteration for Verification

Human Vision Modeling

- Mathematical Models of Human Visual Performance in Response to Stimuli
- Often Empirical in Nature
- Concerned with Color Vision, Spatial Vision, Temporal Vision, Interactions

STIMULUS → BLACK BOX → PERCEPTUAL CORRELATES

Candidate Models

S-CIELAB (Zhang & Wandell, 1995)

S-CIELAB + CIEDE2000 (Johnson & Fairchild, 2002)

CVDM (Jin, Feng, Newell, 1998)

Modular Approach (Johnson & Fairchild, 2001)

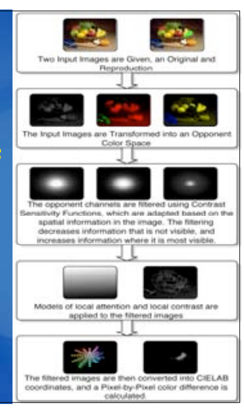
iCAM + Modular (Fairchild & Johnson, 2002)

A Modular Framework

Johnson & Fairchild, CIC 9 (2001)

Modular Framework for IQ Scales

- Promising Framework for Image Differences
- Flexible Implementation



ΔE vs ΔIm

- ΔE (DE) has come to have a specific meaning in color difference measurement.
- True image difference metrics include higher-order processing and should have a different notation.
- **ΔIm (DIm) proposed for image differences.**
- A good ΔIm (DIm) metric will reduce to a ΔE (DE) metric for reference viewing conditions and configurations.

Model Structure

Spatial Filtering, Local Attention, Local & Global Contrast, CIE Color Difference

The Next Step

Unification of Techniques for:

- Color Appearance Specification
- Color Difference Measurement
- Spatial Vision Modeling (Filtering & Adaptation)

RESULT: Image Appearance (& Difference) Model

iCAM

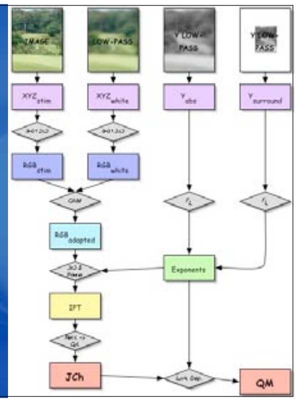
iCAM — *image Color Appearance Model*

A simple framework for color appearance, spatial vision effects, image difference (quality), image processing, and temporal effects (eventually)

An "Image Appearance Model"

Spatial iCAM

Submitted to :
CIC-10 (2002)
CIE Congress (2003)



Sneak Preview

□Im

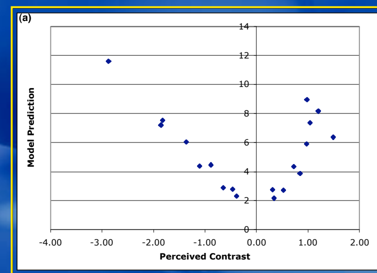
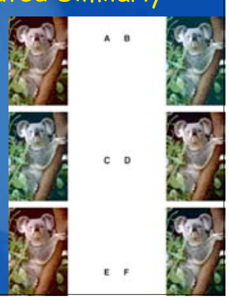


Image Difference Prediction (Contrast Data)

A Word on Preferences

- Preferences can be Treated Similarly
- Difference from Ideal
- “Naturalness”



Research Objectives

- Realization of Device-Independent Image Quality
- Collection of Psychophysical Image Quality and Image Preference Scales
- Formulation of Unified Model for Color Appearance, Image Reproduction, & Image Quality/Differences (an Image Appearance Model)

Outlook (The Light Booth)

Image quality measurement will always require visual evaluation in addition to mathematical modeling just as a light booth is still required for basic colorimetry.

There are always other variables.

Conclusion

- Device-Dependent Image Quality
  - Very Effective for Known or Closed Systems
- Device-Independent Image Quality
  - Necessary for Open Systems
  - Necessary for Revolutionary Systems
  - Necessary for Digital Photography?
- Image Appearance Models will Facilitate DIIQ

Thank You